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INTERCEPTOR CONCEPTS FOR THE US UAV BPI PROGRAM

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Abstract

The Ballistic Missile Defense Organization (BMDO) is managing the US Unmanned Aerial Vehicle (UAV) Boost Phase Intercept (BPI) program. The program's goal is to investigate the potential of UAV-based interceptors to provide a boost-phase defensive tier against theater ballistic missiles. A Technology Assessment and Risk Mitigation Effort is underway to determine the requirements of a UAV BPI system. The Advanced Systems Directorate, Space and Missile Systems Center, Air Force Material Command (AFMC/SMC/ADE) has been selected to lead the interceptor integrated product team (IPT). The interceptor IPT's efforts during its first year have been focused on surfacing attractive interceptor conceptual designs and selecting a preliminary design.

This paper presents the requirements and rationale leading to the preliminary interceptor design. The history of the concept of airborne interceptors for boost-phase defense is briefly reviewed, including how a consensus emerged for the current UAV-based approach. Top-level interceptor requirements are then derived and several concepts are proposed for meeting them. The pros and cons of the alternative interceptor concepts are examined, leading to a single concept. A preliminary interceptor design is then presented for this concept.

Introduction and History

Origin of the Concept -- Peregrine and Raptor/Talon

The concept of using airborne interceptors for theater ballistic missile (TBM) boost-phase defense first appeared soon after Operation Desert Storm. The Aerospace Corporation developed a concept known as Peregrine beginning in October, 1991, and presented it to AFMC/SMC a few months later. Peregrine was presented to the Air Force's Air Combat Command (AFACC) and Aeronautical Systems Center, the Naval Air Warfare Center (NAWC), and many other organizations in the months that followed. It was one of three kinetic energy weapon systems selected for evaluation as a near to mid-term system by BMDO's one year Boost Phase Intercept (BPI) Study, which commenced in October, 1992.[1] Both AFMC/SMC and NAWC sponsored Peregrine during the BPI Study. Originally, Peregrine consisted of a two-stage, 4 sec burn per stage, 5.6 km/sec ideal ΔV, 510 kg, hit-to-kill (HTK) interceptor based on B-52 bombers. Each B-52 carried 16 - 20 interceptors. During the BPI Study, a single stage, 3.1 km/sec ideal ΔV, 135 kg version of the interceptor for basing on manned fighter aircraft (6 per F-15E and F-14D, 3 per F/A-18 and F-16) was added to the concept. The single stage interceptor was simply the original two-stage design less the first stage. The interceptor consisted of several BMDO developed technologies -- Advanced Solid Axial Stage (ASAS) derived booster motors and an Atmospheric Interceptor Technology (AIT) derived 25 kg Kinetic Kill Vehicle (KKV), but with an added axial motor and an uncooled, cavity mounted sapphire seeker window.[2] Both the Peregrine and AIT KKVs employ technologies developed by the KITE/HEDI, D2, Endo-LEAP, LEAP, BP and SBI programs.

During roughly the same timeframe, Lawrence Livermore National Laboratory (LLNL) developed a concept known as Raptor-Talon, which became a BMDO technology program in 1992[3] and was also part of BMDO's BPI Study. Raptor-Talon was the first BPI concept to propose a UAV for the platform. The interceptor was rather exotic -- a 30 sec minimum burn, 3 km/sec ideal ΔV, 20 kg, unitary missile with a sapphire dome seeker window, an aero-spike and a low pressure pumped propellant motor feeding both cruciform divert and axial thrusters. The UAV carried 4 - 6 interceptors, had a wing span of 90 ft, a gross liftoff weight of about 2000 lbm, and loitered at a 20 km (66,000 ft) altitude.[4,5] The Raptor-Talon program ended in 1994.[6]

ABI Program

The BMDO BPI Study concluded Peregrine was a viable, mid-term, Kinetic Energy (KE) BPI concept. The Airborne Interceptor (ABI) program was inaugurated in late 1993 as a joint BMDO/AF Advanced Concept Technology Demonstration program (with Navy participation) to demonstrate such a system. The program subsumed BMDO's AIT KKV program, and baselined a 35 kg KKV with a cooled seeker window. An Operational Requirements Document was approved by AFACC requiring fighter aircraft as the ABI platform and a nominal system standoff range of 250 km against a 600 km range TBM. The interceptor concept was similar to the Peregrine concept -- a 2 stage version for the AF (621 kg, 4.3 km/sec ideal ΔV, 9 sec burn per stage) and a 1 stage version for the Navy (334 kg, 9 sec burn, 3.1 km/sec ideal ΔV).[7,8] The Air Force Scientific Advisory Board (AFSAB) reviewed the ABI program in early 1995 and concluded the concept could be developed and deployed in the near-term with an acceptable degree of risk.[9] Full funding never materialized and the program ended in late 1995.

ARPA/DARO UAV Program

Overlapping the above activities, an aggressive development of UAVs was taking place. These UAVs were relatively small aircraft until the Advanced Research Projects Agency and Defense Airborne Reconnaissance Office kicked off the Tier 2-plus (now known as Global Hawk) program in early 1994. Specific Tier 2-plus mission goals and needs include flying 1000 - 3000 nm to a desired surveillance area at 300 - 400 knots, loitering for at least 24 hr at altitudes up to 65,000 ft; returning to base over a 1000 - 3000 nm egress segment; and operating over a wide area in "all-weather" conditions, with data systems compatible with existing military systems. Meeting these objectives requires a UAV with a gross liftoff weight of about 25,000 lbm and having a wingspan of about 120 ft. Contractors were given a single hard requirement -- design the UAV, including its sensor package and high bandwidth satellite communication (SATCOM) link, to a $10M per aircraft flyaway cost. This assumes the government will buy 10 aircraft in the final program phase for a fixed price of less than $100M.[10] Teledyne Ryan Aeronautical won the phase one design competition in May, 1995, and embarked on phase two -- a 31-month advanced development and flight test program. They will design, build and test two aircraft and a ground station, followed by 12 months of flight and performance testing. Initial flight tests are expected to commence in early 1997.[11]

Lamartin Panel

In early 1995, a panel was convened at the request of Dr. Paul Kaminski, USD for Acquisition and Technology, to review the various KE and directed energy BPI concepts and make a recommendation as to future activities. The panel became known as the "Lamartin Study", after the chairman of its working group, Glenn Lamartin, the Office of the Secretary of Defense's (OSD's) Deputy Director of Strategic and Tactical Systems (Missile Warfare). Two kinetic energy concepts were presented: the ABI concept, and a totally revised "Raptor-Talon" concept (developed by the Army's Space and Strategic Defense Command (SSDC) and LLNL with funding from SSDC and OSD's Counter-proliferation Support Office) consisting of the Tier 2-plus UAV and a 3 km/sec ideal ΔV, KKV-style interceptor with an uncooled seeker window.[12] The Lamartin Panel's conclusion was that a KE BPI using UAVs for the interceptor platform, rather than manned aircraft, provided the lowest marginal cost per platform and provided the only reasonable growth path to deal with theater size limitations, countermeasures and short-burn boosters. They suggested that a meaningful technology program would focus on a lightweight interceptor with a KKV and a speed not much above 3 km/sec, a UAV designed for interceptor launch, a detailed study of CONOPS issues and a flight demonstration when the components were ready. The 3 km/sec interceptor speed was seen as a technology break-point -- the aero-thermal and dynamic pressure environments of a 3 km/sec KKV fired from a high altitude UAV would be comparable to that of the THAAD KKV, the only KKV currently scheduled to be fielded and just beginning flight tests. Greater speeds would require additional technology development, making the system unsuitable for near-term deployment.[13]

Today -- Consensus

At this point in time, a consensus seems to have emerged for the most viable near-term KE BPI concept. Groups such as OSD, BMDO and the AFSAB all agree -- the most viable approach is a roughly 3 km/sec KKV-style interceptor based on a Tier 2-plus high altitude, long endurance UAV. The results presented below tend to confirm this consensus. The fact that both the Tier 2-plus UAV and THAAD KKV will be undergoing flight tests in 1997 substantially reduces the development risk and cost associated with such a UAV BPI system.

In early 1996, at the behest of Congress and with the Lamartin Study's recommendations firmly in mind, BMDO commenced a US UAV BPI program. This effort is focused on developing the requirements and demonstrating key technologies for a UAV BPI system. Integrated Product Teams (IPTs) were formed to provide conceptual designs for the following four areas: CONOPS, UAV, UAV-based Sensors, and Interceptor.

The interceptor requirements are dependent on the attributes of the UAV, UAV Sensors and CONOPS. Deriving them is therefore an iterative process. A short overview of the entire UAV BPI concept (as of mid 1996) will surface the interceptor interfaces and put the interceptor design into context.

UAV BPI Concept Overview

Figures 1 and 2 provide brief descriptions of each major element of the UAV BPI concept. The nominal force structure is 75 UAVs (including 12 spares) and 1200 interceptors. The UAV is a modified Tier 2-plus (Global Hawk). Its reconnaissance sensors and large SATCOM antenna have been replaced by a medium wavelength (3 - 5 μm) infrared search and track (IRST) system with a 1.57 μm wavelength laser detection and ranging (LADAR) system, its radome has been modified and pylons sufficient to attach 6 interceptors have been added. The nominal UAV loiter altitude and speed are 19 km (62,000 ft) and 180 m/s (350 knots), respectively. The vibration and dynamic pressure environments are very benign relative to traditional military aircraft environments, primarily due to the high altitude and mild flight dynamics of the UAV. In clear weather, the UAV IRST/LADAR can detect and track a boosting TBM seconds after liftoff out to ranges of 200 km. Resolution of the sensor measurements is better than 30 m in each axis and revisit rates are nominally 1 Hz. JTIDS is planned for all communication links.

A typical engagement is illustrated in Figure 3. The UAV IRST/LADAR detects the TBM plume, tracks it for several seconds and predicts its future course. An intercept trajectory is computed by the fire control computer and the interceptor is fired. Updates of the target trajectory are radioed to the interceptor until its seeker window is uncovered and it acquires the target. From this point on, the interceptor autonomously homes on the target and attempts to collide with it.

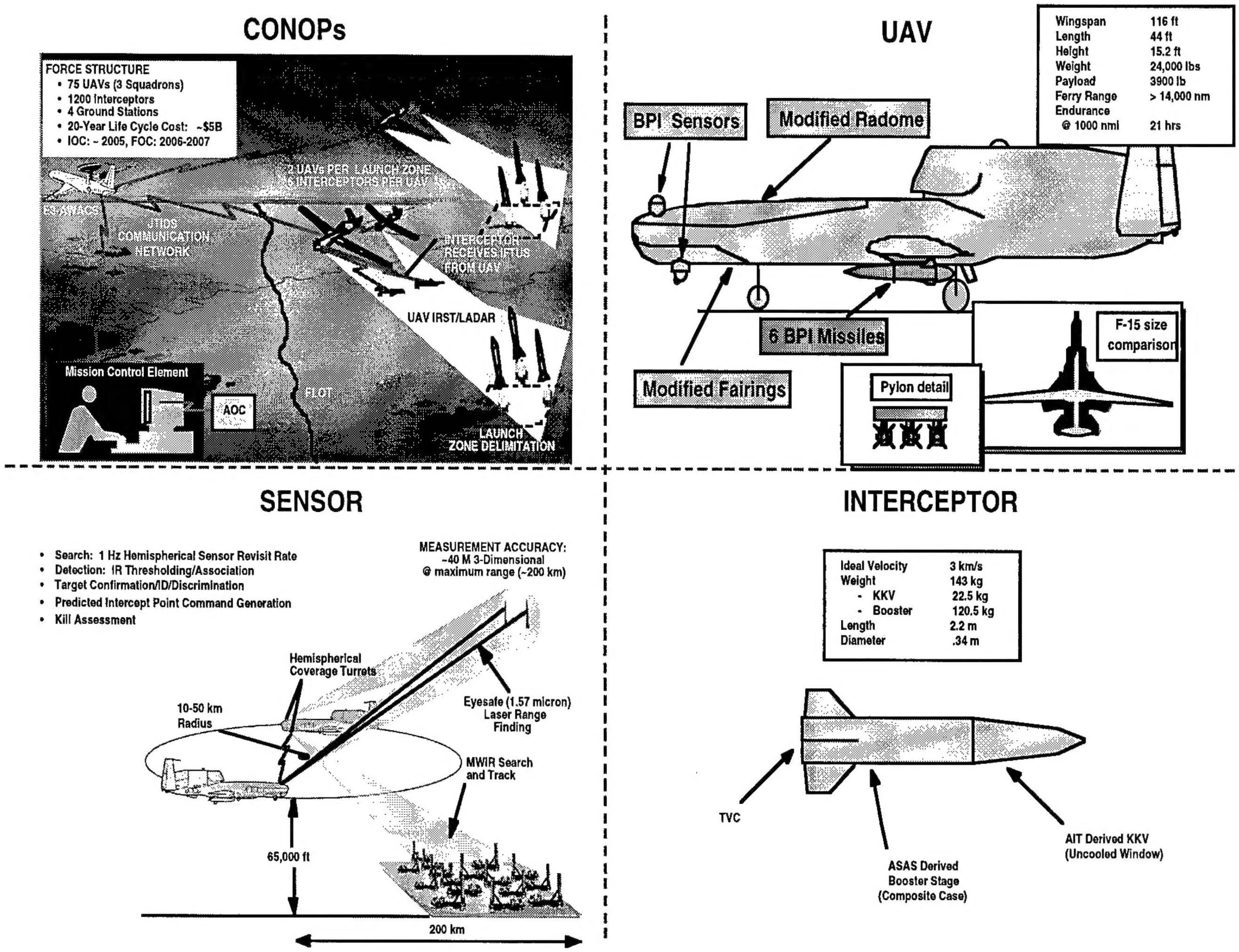
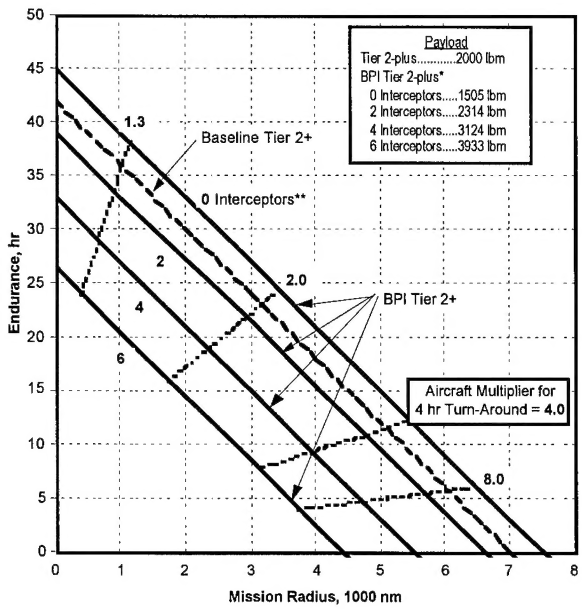


Figure 1. UAV BPI Concept Overview



*143 kg Interceptor + 5 kg Interceptor Boattail + 35 kg Adapter/Pylon = 183 kg = 404 lbm
**Includes 495 lbm of additional fuel

Figure 2. Tier 2-plus Flight Performance

All else being equal, the UAV BPI force structure is about half that of a fighter aircraft type system. This is due primarily to the roughly 21 hour endurance of the Tier 2-plus as compared to the 4 - 6 hour endurance of a typical fighter aircraft. The so-called "aircraft multiplier" (ratio of total number of aircraft to the number of aircraft on-station) is proportional to the aircraft cycle time (service/maintenance turnaround time + ingress/egress flight time + endurance) divided by its endurance. Assuming a cycle time equivalent to the endurance + 4 hours turnaround + 3 hours ingress + 3 hours egress, the Tier 2-plus has an aircraft multiplier of 1.5, while a fighter aircraft has a multiplier of about 3.

Interceptor Top-Level Requirements

The Interceptor IPT began the interceptor conceptual design process by establishing three general requirements:

1. Targets Restricted to Boosting TBMs
2. 2.5 to 3.5 km/sec Ideal ΔV
3. < 200 kg

Note that KKV-style interceptors were not mandated. The rationale for these three requirements deserves discussion.

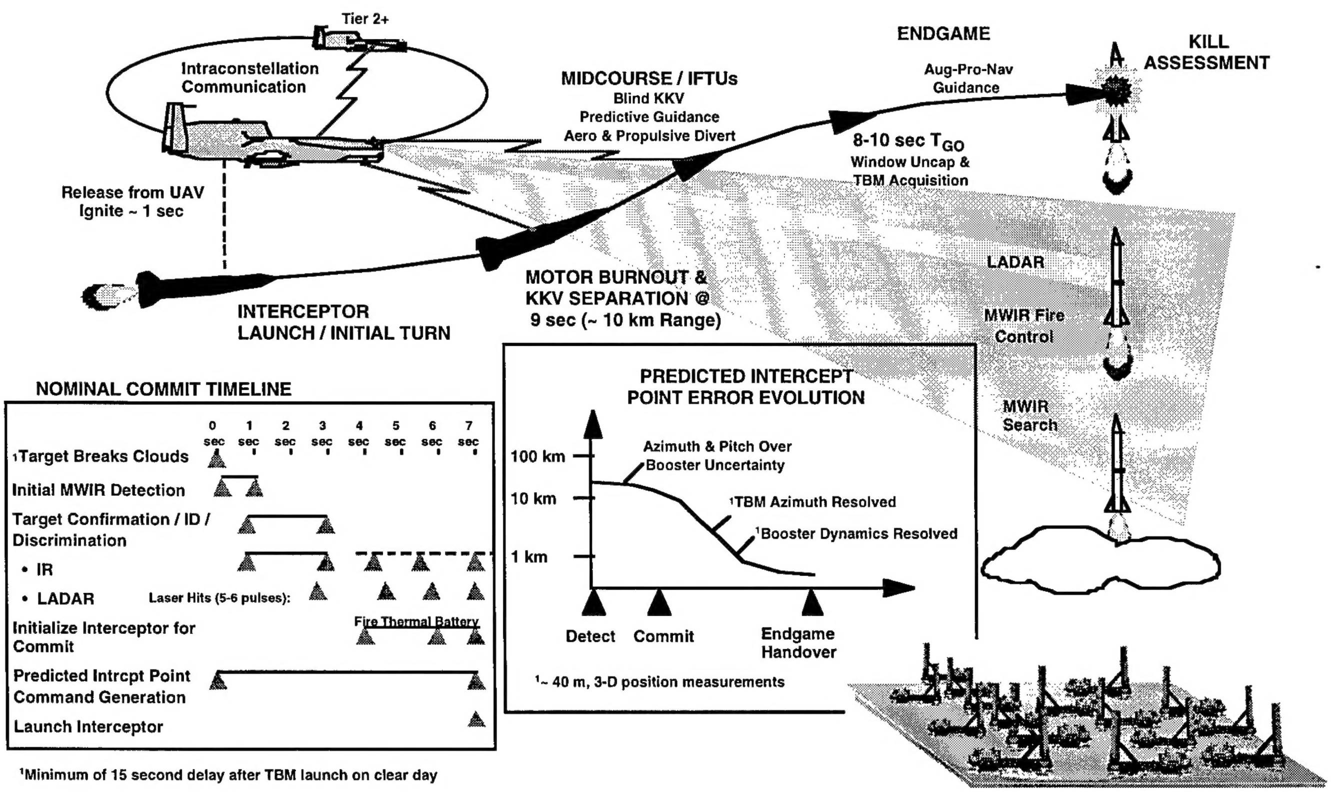


Figure 3. Typical UAV BPI System Engagement

Over the past few years, a BPI system has sometimes been considered synonymous with one that intercepts TBMs prior to the early release of submunitions, which is assumed to occur after booster burnout at altitudes no lower than the "high endo" regime of the atmosphere. These systems must be capable of both boost and early post-boost phase intercepts. The UAV BPI system, however, is a strictly boost phase intercept system. Why? Unlike post-boost TBMs, which have a relatively dim IR signature and must be intercepted in the nose section to achieve a reliable kill, boosting TBMs have extremely bright IR signatures and both the nose section and motor section are viable aimpoints. Although boost phase intercepts are complicated somewhat by the need to a) perform plume-to-hardbody handover, b) hit a high-g target and c) accurately type the target to estimate its burnout altitude (or foregoing this, always intercept at the lowest expected burnout altitude), the majority of interceptor designers nonetheless consider boost phase intercepts less technically challenging, especially from the standpoint of lethality, than post-boost intercepts. Therefore, to achieve the least costly and most near-term interceptor design, the UAV BPI interceptor is required to engage only boosting targets. Once this interceptor design is concluded, its ability to also engage post-boost targets will be evaluated. The decision to make post-boost intercepts a requirement will weigh any increase in interceptor costs against possibly lower system costs steming from the increase in battlespace and the possibly relaxed target typing requirements of a boost plus post-boost interceptor.

Consider now the rationale for requiring the interceptor ideal ΔV to lie between 2.5 km/sec to 3.5 km/sec. The upper bound on interceptor speed is simply an adoption of the Lamartin Study's belief that speeds significantly above 3 km/sec require untested technologies, and therefore would increase the interceptor's cost and/or development schedule. The lower speed bound comes about from its effect on system size or force structure.

Virtually all previous studies of KE BPI concepts have found that a force size greater than about two to three squadrons (50 - 75 aircraft) soon becomes unaffordable, primarily due to recurring logistics and maintenance costs. Since US forces are required to fight two major regional conflicts (MRCs) simultaneously, the UAV BPI system must perform its mission with about 30 aircraft per theater (not including spares). With this in mind, let us calculate approximately how many UAVs are required for a typical theater when the UAVs carry 2.5 km/sec interceptors.

Roughly speaking, Scud-class TBMs have boost phase durations on the order of 70 sec and burnout altitudes of about 35 km. Assuming the TBM launch sites are covered by 6 km altitude clouds, the UAV IRST/LADAR will first detect the TBM at cloud break (~30 sec after TBM launch) and achieve an "interceptor commit quality track" about 40 sec after TBM launch. The time available for the interceptor flyout is therefore roughly 30 sec. An interceptor with an ideal ΔV of 2.5 km/sec will have an average speed of about 1.8 km/sec when flying for 30 sec from an altitude of 19 km to an altitude of 35 km. Its maximum flyout range will therefore be on the order of 55 km. As will be shown later, the interceptor can be designed to lose very little forward speed, and therefore maintain its flyout range, when turning 180 deg. So a UAV's "coverage" against boosting TBMs is roughly a circle with a 55 km radius. Given this coverage, if a TBM launch is equally likely from any part of an area the size of North Korea (121,000 sq km), which is considered a small-size theater, about 14 UAVs 110 km apart must continuously fly over the area. This translates into a total UAV force size of about 21 aircraft (assuming an aircraft multiplier of 1.5). For greater operational flexibility, enhanced survivability and increased effectiveness against TBM salvos (multiple, nearly simultaneous launches from a small area), the UAVs can be deployed in pairs. This doubles the required force size to 42 aircraft, which is already 12 aircraft above the nominal MRC deployment size of 30 aircraft. Figure 4 shows how the total number of UAVs required for a theater varies with ideal interceptor ΔV. Clearly, to meet the goals of deploying the UAVs in pairs and about 30 aircraft per regional conflict requires interceptor speeds of no less than about 2.5 km/sec.

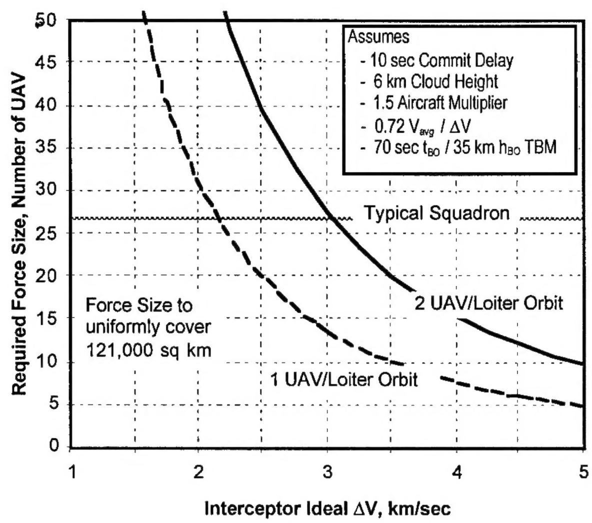


Figure 4. Single Theater UAV BPI Force Size as a Function of Interceptor Ideal ΔV

The above rationale assumed no *a priori* knowlege of the location of TBM launch sites. This is generally not the case, as intelligence preparation of the battle field (IPB) can often delimit the suspected launch locations to select areas. Given a squadron of UAVs, about 10 such select areas can be covered at any one time (assuming 2 UAVs per TBM launch area). The minimum required interceptor

speed is now a function of the uncertainty in the TBM launch location. The interceptor must have sufficient range to compensate for the UAV loiter orbit being out of position with respect to the actual TBM launch point. If IPB can localize the TBM launch point to no smaller than about ±50 km, an interceptor ideal ΔV of roughly 2.5 km/sec is required.

The case for requiring the interceptor ideal ΔV to be at least 2.5 km/sec becomes even more compelling when considering a scenario with higher clouds and an often postulated future threat -- a "short-burn" TBM. If the TBM presented earlier boosts for only 50 sec instead of 70 sec (with no loss in range), then its burnout altitude is reduced from 35 km to about 27 km. If the cloud height is 10 km rather than 6 km, then cloud break occurs at roughly 31 sec. Assuming only 4 sec to obtain a "commit quality track" (we use 4 sec instead of the 10 sec used earlier because the TBM's greater speed now gives a longer and more accurate "track" for a given amount of observation time and because the time over which the TBM's future path must be determined is now shorter), the available interceptor flyout time is cut in half, from 30 sec down to 15 sec. The interceptor flyout range is now roughly 28 km, or about half of the 55 km value obtained earlier. Consequently, since the interceptor's coverage area is now reduced by 25%, the number of UAVs required to defend against "nominal" TBMs launched from an area the size of North Korea must be increased from 21 to 84 when the TBMs are "short-burn" TBMs. And if IPB is to be of value, it must provide the TBM launch locations to about ±25 km or less. Clearly, an interceptor ideal ΔV of 2.5 km/sec produces UAV force sizes and IPB requirements that are barely manageable; establishing 2.5 km/sec as the ideal ΔV lower bound is therefore very reasonable.

Let us now address the rationale for setting the maximum interceptor mass at 200 kg. Like the speed requirement, this requirement also comes about from the desire to minimize force structure and total system cost. If we assume a UAV is always placed near enough to a TBM launch site to ensure the TBMs launched from that site are engagable (i.e., the launch site is within UAV coverage), a basic tradeoff presents itself -- how many interceptors of a specified mass must each UAV carry (the so-called interceptor loadout) to 1) minimize the number of UAVs per loiter orbit (or the number flying together as a unit), and 2) engage reasonably sized TBM salvos? The fact that an optimum number of interceptors per UAV exists can be readily shown. If a UAV carries only 1 interceptor, then the loiter orbit must contain 1 UAV for each TBM in a salvo. Salvos with up to 10 TBMs would require 10 UAVs per loiter orbit and the system cost per TBM would obviously be very high. On the other hand, if each UAV carries so many interceptors that fuel has to be off-loaded to maintain the UAVs maximum liftoff weight, and the fuel loss drops the UAV's endurance from 24 hours to, say, about 6 hours, then the aircraft multiplier doubles and so does the size of the total UAV force. Again, the system cost per TBM becomes very large. Figure 5 shows the system cost per TBM for interceptor masses of 100 kg, 150 kg and 200 kg. Note that the minimum cost is a function of several parameters: the number of interceptors per UAV, the mission radius (distance from UAV airbase to TBM launch site), the UAV and interceptor unit costs, and the mass of the interceptor. The system cost per TBM minus $1M (the cost per TBM of an interceptor) is the cost per TBM of the UAVs. The total required number of UAVs at each cost minimum is shown in the figure. A key result is the greater the interceptor mass, the greater the required minimum number of UAVs and the greater the minimum system cost per TBM, all else being equal. The relationship is almost one-for-one; doubling the interceptor mass nearly doubles the required minimum number of UAVs. Therefore, it is paramount to keep the interceptor mass as low as possible. At a mission radius of 1000 nm and an interceptor mass of 200 kg, the system of minimum cost has a total UAV inventory of just over 100 UAVs. This force size is considered an upper limit for the UAV BPI system; the costs associated with production and especially operations and maintenance become unaffordable for larger force sizes. Thus, the maximum interceptor mass is set at 200 kg.

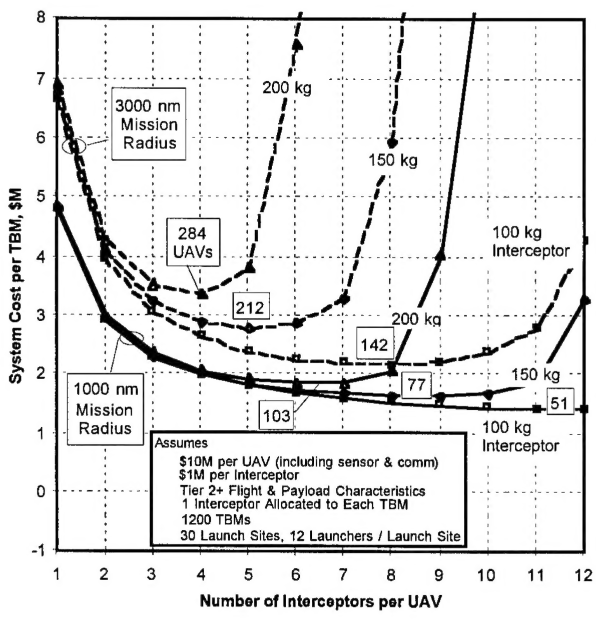


Figure 5. UAV BPI System Cost per TBM as a Function of Number of Interceptors per UAV, Interceptor Mass and Mission Radius

Another key result of Figure 5 is the optimum value of the number of interceptors per UAV. This quantity is primarily a function of the mission radius and the interceptor mass. In fact, to first order, one can show that

the number of interceptors which minimize the system cost per TBM is inversely proportional to the product of the mission radius and the interceptor mass. As the results show, 6 interceptors per UAV is a reasonable value for the parameter ranges of interest. If 2 UAVs are assigned to each loiter orbit, then 12 interceptors are available for a TBM salvo. This also appears to be a reasonable result.

Interceptor Feasibility Trades

Once the top-level interceptor requirements were established, the interceptor IPT evaluated the feasibilty of a variety of different interceptor concepts to meet these requirements. The trade space included exisiting air-to-air missile (AAM) front-ends and motors, AIT-like KKVs with uncooled seeker windows, ASAS-like motors, and HTK concepts versus concepts carrying a warhead. A summary of all the options considered and how they stacked up against the top-level requirements is given in Table 1. As the table shows, existing AAM front-ends mated with existing AAM motors, stretched AAM motors,

Table 1. UAV BPI Interceptor Feasibility Trades

Interceptor Design Option	Can Design Withstand Heating Created by Speed of 2.5 km/sec?	Can Design Achieve a Total Mass < 200 kg and Ideal ΔV of 2.5 km/sec?*
Exisiting Air-to-Air Missile	NO	NO
Stretched Air-to-Air Missile	NO	NO (due to need for Warhead)
Stretched Air-to-Air Missile with Newly Developed Window/Radome Cooling Technology	YES	NO (due to need for Warhead)
ASAS Motor(s) with Air-to-Air Missile Front-end Including Newly Developed Window/Radome Cooling Technology	YES	NO (due to need for Warhead)
ASAS Motor(s) plus Separating Kill Vehicle with a Warhead	YES	NO
ASAS Motor(s) plus Separating Hit-to-Kill Kill Vehicle (Kinetic Kill Vehicle)	YES	YES

*Equivalent to achieving a payload mass of under 40 kg for a state-of-the-art 2.5 km/sec ideal ΔV missile (see Figure 6)

or state-of-the-art ASAS motors cannot achieve speeds of 2.5 km/sec and weigh under 200 kg. And even if they could, these existing front-ends cannot travel at speeds above about 2 km/sec without causing their seeker windows or radomes to experience excessive thermal stress.Only an interceptor with a front-end employing the miniaturized components developed by BMDO over the past decade has a chance at meeting the 200 kg / 2.5 km/sec requirement. And as Figure 6 shows, this front-end cannot exceed about 40 kg.

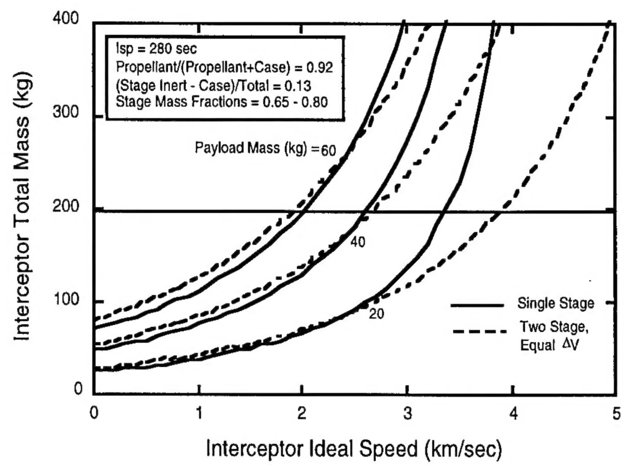


Figure 6. Interceptor Mass as a Function of Ideal ΔV, Payload Mass and Number of Stages

Only two airborne interceptor designs, both of which have never been demonstrated, appear to be feasible in the near-term:

1. A unitary missile (front-end does not separate) with a state-of-the-art motor and a front-end (including warhead if required) weighing 40 kg or less. Steering is accomplished by pulling angle of attack using thrust vector control (TVC), aero surfaces or small thrusters, limiting this design to altitudes below about 30 km. A warhead is probably required since the vehicle time response may be inadequate to provide HTK.

2. A staged missile (front-end separates) with a state-of-the-art motor and a front-end, or Kill Vehicle (KV), weighing 40 kg or less. The KV is a self-contained miniaturized interceptor with seeker, flight computer and guidance and control. Steering prior to KV separation is accomplished by pulling angle of attack (using TVC, aero surfaces or small thrusters). Two KV designs are feasible:

a. A HTK KV, or KKV, employing propulsive divert for steering. This KV must be HTK, as the addition of a warhead causes the KV weight to exceed 40 kg. Note that a propulsive divert KKV is not altitude limited.

b. A KV employing aerodynamic divert for steering. This design could possibly accomodate a small warhead. Its altitude is limited to about 30 km.

At this point, proceeding forward with a preliminary interceptor design requires selecting one of the above three concepts. The technology base exists to develop each of these 3 concepts, and broadly speaking, the development required for each is roughly comparable (i.e., all three require a lightweight front-end and a new state-of-the-art motor). Therefore, the one with the largest potential battlespace and the most growth potential was selected for the UAV BPI system. Only option 2b -- a KKV atop a booster motor -- has the ability to intercept TBMs at altitudes above 30 km. As a result, it has a potentially much larger boost phase battlespace than the other two options, and does not close the door on the possibility of performing post-boost intercepts should later analysis show this to be desirable.

Preliminary Interceptor Design

Space does not permit a detailed discussion of the preliminary UAV BPI interceptor design, but some of the basic trades and conclusions deserve mention. The design has an ideal ΔV of 3.0 km/sec and a total mass of 143 kg. For reasons discussed below, speeds above 3.0 km/sec resulted in interceptor weights above 200 kg, and were therefore unacceptable. Speeds as low as 2.5 km/sec could have been selected, but were discarded because of the reduced UAV coverage they provide.

The IPT began its KKV design process by reviewing the results of the AIT program. Since its inception in 1992, the BMDO AIT program has invested 4 years and over $100M in the design of two lightweight endo/exo KKVs, one by McDonnell Douglas and the other by Lockheed-Martin. When part of the ABI program, the AIT KKV design requirements included HTK of boosting TBMs, flight times of up to 100 sec, loads of up to 100 gs axial and 30 gs lateral, and full functionality when traveling at 4 km/sec at an altitude of 25 km. To meet this last requirement, each AIT contractor included a cooled seeker window in their KKV designs. The UAV BPI interceptor IPT has taken full advantage of the work accomplished by the AIT program. The best features of the 2 AIT KKVs were identified and merged into a single design. The cooled seeker window was replaced by an uncooled window to reduce the KKV and interceptor mass, as well as the KKV development risk. This required limiting the KKV speed to about 3 km/sec, a value within the established UAV BPI design requirements. The lower KKV speed allowed the KKV structure and thermal protection system to be lightened, reducing the KKV mass even more. The final result was a 22.5 kg KKV, shown in Figure 7. Table 2 gives some additional details about the design. The design of the interstage between the KKV and booster motor came in at 2.5 kg, so the total payload weight for the booster motor was 25 kg.

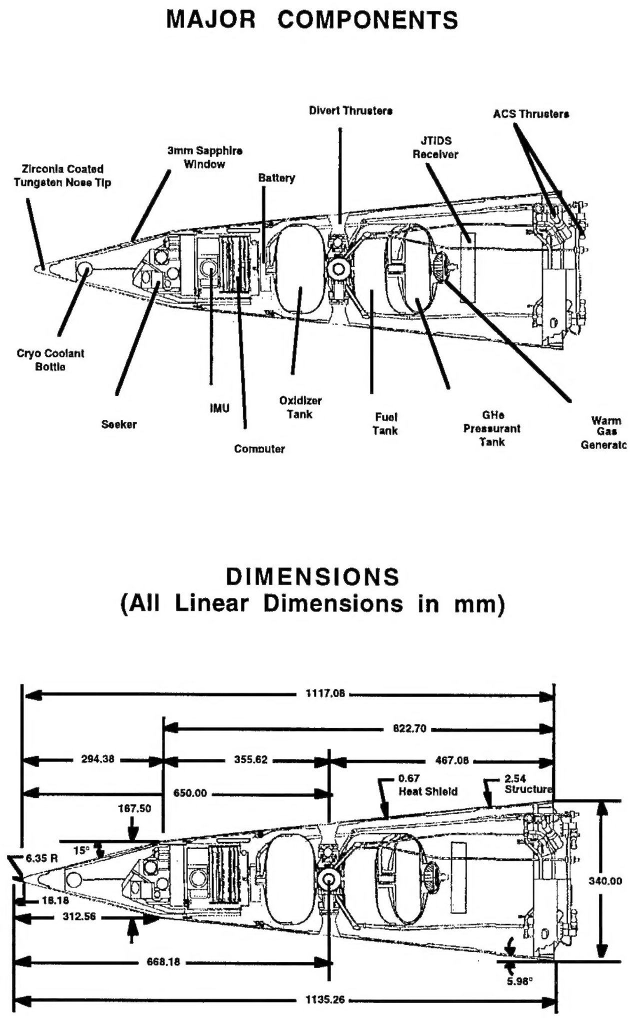


Figure 7. UAV BPI Interceptor KKV

Over 24 different booster motor designs and configurations were analyzed. A major design goal was the ability to perform a 180 deg turn with little loss in engagement range. The trade space included 1 versus 2 stages, titanium versus composite cases, TVC versus aero-control surfaces, and stabilizing fins versus a stabilizing

Table 2. Preliminary UAV BPI Interceptor KKV Characteristics

Component	Primary Material	Specifications	Mass (kg)
Seeker System	Aluminum	3-4 μm, 2° FOV, 3°-50° FOR, 30 fw/cm^2 NEI, HgCdTe, 256x256, 100K, 23μsec to 3.9msec, 3 mm x 40 mm x 100 mm Sapphire window	2.453
Avionics			4.880
Power	Aluminum	28 V, 7000 W-sec	1.315
IMU	Aluminum	1 deg/hr, 0.1 deg/$\sqrt{hr}$, 1.5 mg, 300 ppm	0.975
Computer	70% Aluminum, 30% Silicon	32 bits, 4 Mbytes, 20 MIPS	1.000
IFTU Receiver	70% Aluminum, 30% Silicon	JTIDS	1.590
Forebody			1.529
Nose Tip	Tungsten/Zirconia	0.635 cm nose radius	0.200
Structure	Berrylium	15°, 16.75 D X 29.44 L X 0.254 cm	0.980
Insulation	Rubber Modified Silica Phenolic	0.130 cm	0.199
Misc (attach H/W)	Aluminum		0.150
Aft Cone			3.139
Shell	Beryllium	16.75 D X 82.27 L X 34.00 D X 0.254 cm	1.866
Insulation	Rubber Modified Silica Phenolic	0.067 cm	0.663
Aft Bulkhead & Misc	Aluminum		0.610
Propulsion/ACS			10.499
Dry			5.006
Oxidizer Tank	Graphite Epoxy	19.25 D X 9.53 cm L (2737 cm^3)	0.485
Fuel Tank	Graphite Epoxy	19.25 D X 9.92 cm L (2229 cm^3 is fuel)	0.403
GHe Tank	Graphite Epoxy	part of fuel tank (650 cm^3), 5000-10000 psia	0.418 (part of fuel tank)
Solid Propellant Gas Generator	Titanium	0.200 kg propellant	0.250
Misc (nozzles, valves & plumbing)	C/SiC nozzles, Titanium for rest	270 sec Isp, 695 m/sec ΔV	3.450
Consumables			5.493 (5.195 usable fuel)
Oxidizer	gelled IRFNA	2000 psia combustion chamber	3.572
Fuel	gelled MMH	2000 psia combustion chamber	1.623
Pressurant	GHe	5000-10000 psia	0.099
Solid Propellant Gas Generator	70% AN / 30% HTPB	10000 psia combustion chamber	0.050
Trapped			0.149
Mass Fraction		0.5232	
Total KKV (not including interstage)			22.500

flare. TVC with stabilizing fins produced the best balance between manueverability and low weight. The result of the remaining trades is summarized in Figure 8. A single stage, composite case motor (with fins) produced the lowest weight design and had acceptable levels of near-term development risk. Figure 9 shows the preliminary interceptor design and provides some of its specifications.

When developed, the UAV BPI interceptor could be the first airborne interceptor with a fully composite motor case, which has often been cited as a concern. Most of the concern involves the integration of launcher/ejector attachments into the case, handling characteristics, and susceptibility to fatigue from thermal/vibration/shock cycling. The AF conducted a major study of these issues and found that they are managable; consequently, the AF concluded that composite motor cases can be designed to meet air-launch requirements.[14] The UAV BPI air-launch requirements are significantly less stressing than those of traditional air-launch missiles because the Tier 2-plus aircraft provides a low dynamic environment, and its large electrical power output can accomodate a heating system to mitigate thermal cycling of the interceptor.

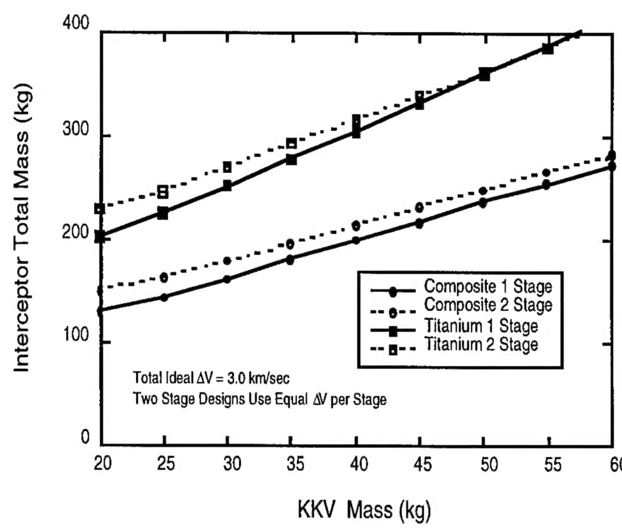
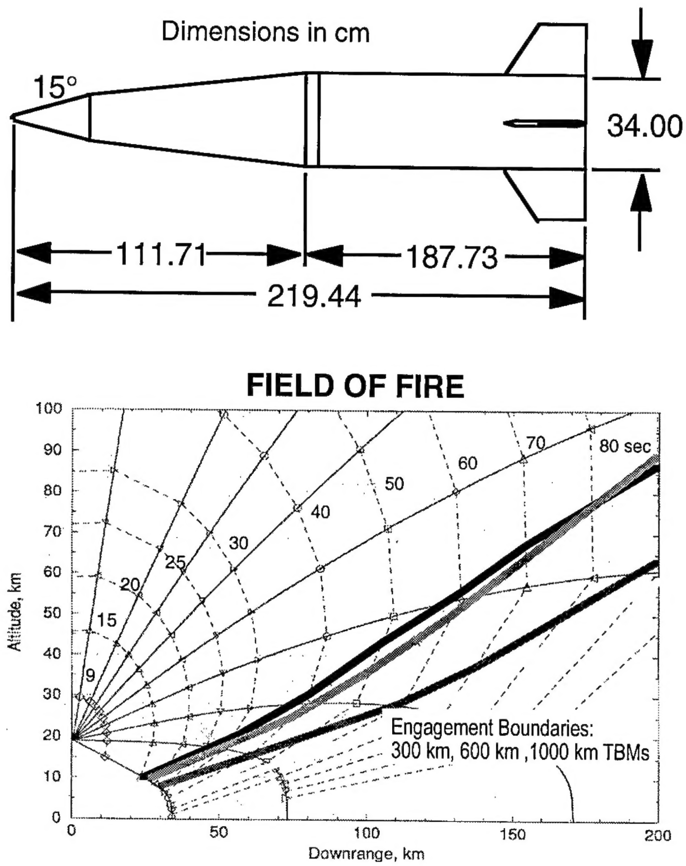


Figure 8. Interceptor Mass as a Function of KKV Mass and Some Design Options

Summary and Future Work

A preliminary interceptor design for the UAV BPI Technology Assessment and Risk Mitigation Effort has been completed, resulting in a 22.5 kg KKV atop a single stage, composite case motor. The interceptor weighs 143 kg and has an ideal ΔV of 3 km/sec. It incorporates many of the features of prior KE BPI concepts, including the first such concepts -- Peregrine and Raptor-Talon in 1992 -- and the later ABI concept of 1994-1995.

Refinements of the preliminary interceptor design are currently in progress. The most significant modification being considered is the addition of an axial motor to the KKV. The greater freedom of action this provides to the KKV may increase the interceptor battlespace beyond the present capability and also provide enhanced lethality against TBM warheads.



Description	SI Units	English Units
Total Missile		
Ideal ΔV	3.00 km/s	6711 mph
Total Mass	143.0 kg	315.2 lb
Total Length	2.19 m	86.5 in
Max Body OD	0.34 m	13.4 in
OD with Fins	0.72 m	28.3 in
KKV		
Ideal ΔV	600 m/s	1970 ft/s
Mass	22.5 kg	49.5 lb
Length	1.12 m	44.0 in
Base Diameter	0.34 m	13.4 in
Nose Angle	15°	15°
Booster		
Total Mass	120.50 kg	265.1 lb
Case Mass	6.44 kg	14.2 lb
Propellant Mass	95.10 kg	209.2 lb
Interstage Mass	2.50 kg	5.5 lb
Roll Control	2.30 kg	5.1 lb
Misc Mass	14.16 kg	31.14 lb
Mass Fraction	0.79	0.79
Isp (vacuum)	280 s	280 s
Burn Time	9 s	9 s
Thrust (vacuum)	29.0 kN	6527 lbf

Figure 9. UAV BPI Interceptor Preliminary Design

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